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ABSTRACT

In general, people seem to be poor at noticing analogies, especially when they are required to apply an analogy to a domain that is new. It was suspected that schemas influence the noticing and applying of analogies. Schemas are hypothesized to be abstract propositional structures that emphasize relationships among categories of objects rather than specific objects and their actions. Two experiments were conducted to manipulate the likelihood of schema formation and to assess the effects of schemas on analogical problem solving. Schemas were hypothesized to be abstract propositional structures that emphasize relationships among categories of objects rather than specific objects and their actions. In experiment I, instructions and the number of stories were manipulated to form a 2x2 design. The performance of two-analog comparison versus two-analog no-comparison groups suggested that a schema may aid in the noticing of analogies, but not in the application of an analogy. Experiment II was designed to investigate additional processing done by "comparison" subjects in the original experiment. All subjects in the second experiment read two analogs and wrote summaries of them, and compared or did not compare the stories. Within four resulting groups, subjects were either given the target problem or were asked to report back one week later. There was no difference in performance between the delay and no delay groups in solution rates. Results of both experiments suggested that schemas are most helpful, at least for novices, in applying analogies as opposed to the initial noticing of analogies. Analogs and problems used are appended. (LMO)

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The Role of Schemas in Analogical Problem Solving

by

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Abstract

In general, people seem to be poor at noticing analogies, especially when they are required to apply an analogy to a domain that is new. We suspect that schemas influence the noticing and applying of analogies. Schemas are hypothesized to be abstract propositional structures that emphasize relationships among categories of objects rather than specific objects and their actions. In two experiments we sought to manipulate the likelihood of schema formation and assess the effects of schemas on analogical problem solving. The results suggest that schemas are most helpful, at least for novices, in applying analogies as opposed to the initial noticing of analogies.

Why do some people think of Romeo and Juliet when they go to a performance of West Side Story? Why do others fail to notice the similarity unless reminded? Why is a seemingly simple statistics problem answered incorrectly by statistics majors? The answers to these questions require an exploration in the domain of analogical problem solving. In some sense, an analogy is a state of mind: the individual notices some similarity between a current stimulus and an old stimulus. This similarity may be useful in which case the information the individual recalls will aid him or her in dealing with the current stimulus. Thus he or she might recall a statistics problem or a particular story that helps solve or make sense of the current problem or story. However, in other cases the recalled piece of information may only bear a superficial similarity to the current stimulus. In these cases, the recalled information will hinder the individual in dealing with the stimulus. In still other cases, the current stimulus might not lead the individual to recall any similar examples, useful or otherwise.

We abstract information from problems and events. This abstracted information then cues older information we have stored. The older information may help or hinder the problem solving process depending on whether the information is the *right* information. Sometimes people seem quite poor at coming up with the appropriate old information. Our research has been aimed at discovering some of the factors that influence peoples' performance at reasoning analogically.

Prior work on transfer has suggested that people are not very adept at spontaneously retrieving appropriate analogs. For example, Gentner and Gentner (1983) found that subjects typically did not spontaneously notice an analogy between water flow and the flow of electricity even though the relevant information was presented to subjects in close temporal proximity to the electricity problems subjects attempted to solve. Weisberg, DiCamillo, and Phillips (1978) found that subjects were unlikely to spontaneously see that a previously learned paired associate would aid them in solving Duncker's (1945) candle problem.

Fortunately, the news is not all bad. The findings of Gick and Holyoak (1980, 1983) support the notion that people with an abstract schema for a problem type can apply an analogy to a target problem better than people who have only specific, concrete analogs in memory. They found that manipulations designed to encourage abstraction of schemas improved subjects' performance on target problems. I propose that schemas are abstract propositional structures that emphasize relationships among categories of objects rather than specific objects and their actions.

In several of the Gick and Holyoak (1983) studies, experimental subjects read two stories describing how a person solved a particular problem such as capturing a fortress or putting out a barn fire. These problems were designed to be analogs in that the solutions involved similar principles although they were applied in different domains. In both cases, the problem was solved by having forces (such

as troops of soldiers or buckets of water) converge on a central target (the fortress or the barn, for example). Control subjects read one of the above stories (or one similar to them) and also read a control story that was unrelated to the analogs. All subjects summarized whatever two stories they read and then also wrote down how they felt the two stories were similar. Subjects were then given the target problem and asked to generate solutions to it. The target problem was designed to be analogous to the two stories the experimental subjects read and, therefore, analogous to one of the stories the control subjects read (see Appendix for the target problem and the stories). After generating their solutions, subjects were then given a hint to consider whether the prior stories might be used to solve the current problem. Gick and Holyoak (1983) argued that the number of subjects who solved the target problem **before** the hint serves as a measure of how well subjects **noticed** the analogy. The number of subjects who solved the target problem **after** the hint serves as a measure of how well subjects could **apply** the analogy.

The "two-analog" group came up with the analogous convergence solution to the target problem significantly more often than the "analog-control" group, both before and after a hint. (Note: "solutions after a hint" refers to the total number of people who produced the convergence solution after the hint including those subjects who also produced it before the hint). In addition, subjects' written comparisons of the stories were examined as a way of roughly determining the presence and quality of the convergence schema (see Gick and Holyoak, 1983 for a

description of the scoring criteria). The researchers found that subjects whose comparisons contained a clear reference to the convergence schema tended to produce the convergence solution to the target problem more often than subjects whose comparisons did not contain this reference.

The above results are taken as evidence that people reason by analogy most successfully when they have abstracted a schema from earlier problems. As Gick and Holyoak (1983) note: "In general, mapping an analog to a schema will be simpler than mapping one analog to another, because in the former case it will only be necessary to map identities, rather than both identities and differences" (p 10). Schemas are hypothesized to be largely domain independent and thus can be cued by higher-order relationships in a problem more easily than specific analogs that are constructed primarily with domain-specific information. These analogs could be cued by surface features of the target problem, but would not be cued by any deep structure propositions that might be formed from the target problem.

However, one alternative explanation for the results is that the experimental subjects may have performed better than the control subjects simply because they had been exposed to two useful analogs while the control subjects had been exposed to only one analog. Subjects in both groups may have been reasoning directly from the prior analogs to the target problem. The reason the two-analog group did better may be because they had two opportunities to find something useful to help them with the target problem while the one-analog group did not. Thus, schemas

may have played no role in the problem-solving process. In order to test this alternative explanation, we conducted an experiment designed to affect the likelihood of subjects forming schemas.

Experiment I

Method

Subjects. 80 University of Michigan undergraduates participated in the experiment as part of a course requirement.

Procedure. We manipulated instructions and the number of stories, forming a 2x2 design. Half the subjects read two analogs while the other half read one analog and one control story. Additionally, within each group, half the subjects received instructions to compare the stories for similarities while half did not. It was hypothesized that "comparison" subjects would be more likely to form schemas than "no-comparison" subjects. As in Gick and Holyoak (1983), all subjects wrote brief summaries of the stories to encourage a reasonable amount of processing. All subjects were then presented with the target problem. After subjects had generated solutions, they were asked to try to come up with a solution that might be suggested by one or both of the prior stories.

Results

Among subjects who received two analogs, those who compared the stories explicitly came up with the convergence solution to the target problem significantly more often than subjects who did not do an explicit comparison (see Table 1).

However, this difference was significant only **before** the hint (60 vs 25%), $G^2(1)=5.13$, $P<.024$. (G^2 is a maximum likelihood statistic.) After the hint, both groups performed about the same (90 vs 80%), $G^2(1)<1$. The comparison instructions had no effect on subjects who received one analog and one control story (see Table 1).

Insert Table 1 about here

A comparison of the two-analog subjects who did not receive comparison instructions with the analog-control subjects (collapsed across comparison instructions) shows that there was a significant difference in the generation of the convergence solution **after** a hint (80 vs 38%), $G^2(1)=10.17$, $P<.2015$, but not **before** a hint (25 vs 20%), $G^2(1)<1$.

Discussion

The performance of the two-analog comparison versus two-analog no comparison groups suggests that a schema may aid in the **noticing** of analogies but not in the **application** of an analogy. That is, a schema may aid someone in noticing the relevance of an analogy, but once someone is made aware that some prior information is relevant to a new problem, he may be able to discover the analogy and apply it to the problem regardless of whether or not he has previously abstracted the relevant higher-order elements (from the prior problems) that make

up the schema. In contrast, the comparison of the groups that presumably did not form schemas, the two-analog no-comparison group and the analog-control group, suggests that the **number** of prior problems seems to influence the **application** of analogies (cf. Ross, 1984). That is, the more experience a person has with problems that share a particular underlying principle, even if the person is not initially aware of the principle, the greater the chance that person will be able to take the information from at least one of the prior problems and apply it to a new problem if he is told that the old problem is relevant.

The results from this experiment support the idea that schemas play a role in reasoning by analogy, particularly in noticing analogies. Additionally, the number of prior examples seems to influence one's success in applying an analogy, once noticed.

While research using other materials must be conducted in order to allow generalizations for these findings, there are several more issues that have been explored using the framework provided by the studies mentioned above. One issue is the effect of the surface similarity of the analogs on the construction of a schema. Prior work has suggested that dissimilar training examples make it more difficult for people to learn a concept, but once they learn it they are able to apply it to more varied situations than people who learn a concept via similar training examples (Posner & Keele, 1968; Fried & Holyoak, 1984). Gick and Holyoak (1983) looked at this issue by comparing subjects who received either two similar

analogs (either two military stories or two fire-fighting stories) or two dissimilar stories (one military story and one fire-fighting story). They did not find any consistent difference among the groups in terms of solution rates or in schema quality. However, their sample was small, so this issue is re-examined in the experiment to be described below. Before describing the experiment, additional issues should be addressed.

One feature of all the experiments discussed so far has been that subjects read the base analogs and the target problem during the same experimental session. This causes three difficulties for subsequent interpretations of the results. The first difficulty is that experimental demand may lead subjects to consider how the prior stories might relate to the target problem. These same subjects might not do this in a more realistic situation. Thus, the effect of the comparison instructions could have been obscured in the above experiment. The second difficulty is that, among the two analog subjects, those who received comparison instructions might have been inclined to compare the individual analogs to the target story simply because the prior comparison between the stories was rewarding. The third difficulty is a more theoretical one: it might be easier and more efficient to reason from a concrete analog than from a schema when the base analogs are relatively fresh in memory. The prior experiments were based on an assumption that people would reason from a schema if they had one. However, perhaps it is sometimes easier to reason from an example if the example is fresh in memory, even if the

schema is also fresh. Thus, the prior experiments may not have optimally tested the question of whether schemas play a role in reasoning by analogy.

One further issue also concerns methodology. "Comparison" subjects do additional processing of the stories when they write the comparisons. This additional processing may have led these subjects to process the stories more deeply than the "no comparison" subjects and thus made the analogs more salient. This increase in availability could improve solution rates without the use of a schema. The next experiment was designed to examine these issues.

Experiment II

Method

Subjects. 222 University of Michigan undergraduates participated in the experiment as part of a course requirement.

Procedure. All subjects read two analogs and wrote summaries of them. Subjects either received two similar analogs (military stories or fire-fighting stories) or two dissimilar analogs (one military story and one fire-fighting story). Within those groups, subjects either explicitly compared or did not compare the stories. Subjects who did not compare the stories were asked to write an additional summary of each, but for this second summary they did not have the stories in front of them for reference. Finally, within these four groups, subjects either were given the target problem or the were asked to report back one week later for a separate experiment. This last manipulation provided a delay **and** a release from

experimental demand because subjects knew they were participating in several experiments at the same time and had no reason to believe that the experiment they were reporting to the following week would be related to the one they had just "finished." Note, however, that even subjects in the no delay condition were shielded from experimental demand since they too knew they were participating in several experiments during the same session. In sum, the experiment was a 2x2x2 (stories x comparison instructions x delay) design as shown in Figure 1.

Insert Figure 1 about here

Results and Discussion

There was no difference in performance between the delay and no delay groups in solution rates either before or after the hint. This was a surprising finding since, on first pass, it seems reasonable to expect a decrement in performance by the delay group due to decreasing availability of the stories and any schema that had been formed. However, the work of Posner and Keele (1970) suggests that a "schema pattern" is less subject to loss over time than individual instances. Since no difference in performance was found along this dimension in our experiment, subsequent analyses are collapsed across it. There was also no difference in the frequency of the convergence solution as a function of the surface similarity of the stories. While subjects who read two military stories tended to

produce better written schemas than subjects who read two fire-fighting stories or one military and one fire-fighting story, there were no differences among these subjects in the frequency of the convergence solution. The fact that the two-military story subjects produced better written schemas may be due to an artifact in the stories rather than the true abstraction of a schema. This issue is discussed further in Gick and Holyoak (1983).

The general finding of major interest was also a surprise given the results of the prior experiments: there was no difference between the compare and no compare groups (collapsed across the delay and story type dimensions) before a hint (20 vs 16%), $G^2(1)<1$, only after a hint (70 vs 51%), $G^2(1)=5.87$, $p<.016$ (see Table 2). This suggests, using the logic described earlier in the paper, that schemas aided in the application of the analogy but not necessarily in the initial noticing of the analogy. The same result obtains when looking at solution rates as a function of schema quality. There are no differences in solution rates for subjects with poor, intermediate, and good schemas before a hint, (20 vs 17 vs 26%), $G^2(2)=1.11$, but there are large differences after a hint (54 vs 87 vs 74%), $G^2(2)=18.86$, $p<.0002$ (see Table 3). That is, in general, the better the schema, the more likely a person will be able to apply the analogy to the target problem. These results conflict with those in Experiment I where the effect of instructions was before the hint.

Insert Table 2 about here

Insert Table 3 about here

Why do these results occur? There are several possible explanations, although only a brief discussion is feasible here. An obvious explanation is based on the decreased role of experimental demand in Experiment II. Subjects in Experiment II knew they were participating in two or three experiments at the same time with the same experimenter. They were answering questions, making judgments, writing summaries, and solving problems in the same session. We think we successfully decreased the probability that subjects would consider using the prior stories on the target problem just on the basis of having read the stories in the same environment as the problem (of course, for the delay subjects, the stories were read in a different session than the target problem). The fact that subjects with schemas could apply the analogy, once reminded, does suggest that schemas do aid in problem solving once they are retrieved. Nevertheless, it is puzzling why, in the before hint condition, a reasonable percentage (60) of the comparison condition subjects in Experiment I generated the convergence solution while a much smaller percentage (20) in Experiment II generated the solution.

However, experimental demand may have made the *before* hint condition of Experiment I roughly equivalent to the *after* hint condition of Experiment II. In some sense, there was no true "before hint" condition in Experiment I. This would explain the superior performance of subjects in Experiment I (see Figure 2). The results of Experiment II, then, seem the most secure.

Insert Figure 2 about here

General Discussion

It is clear that schemas play a role in analogical problem solving. The question now becomes: What is their exact role? Research in expert/novice differences suggests one way to consider the role of schemas in problem solving. The work of Chi (Chi, Feltovich, & Glaser, 1981; Chi, Glaser, & Rees, 1983), Larkin (Larkin, McDermott, Simon, & Simon, 1980) and others suggests that experts in a particular domain solve problems through the activation of high level schemas that organize the information in that domain in a useful way. Novices, on the other hand, organize their information in the domain by surface features of the few problems they have encountered in the past. Schemas made of abstract propositions get activated for experts because the target problem is encoded abstractly, that is, the problem is seen as an instance of a certain category. Novices, on the other hand, may only recall other problems that are similar in

superficial ways (at least from an expert's perspective) to the target problem since the target is represented by propositions that are not very abstract. In both cases, the information that gets activated is a function of how abstractly the current problem is represented in addition to the abstractness of the information that exists to be activated (Gentner & Gentner, 1983; Tenney & Gentner, 1984; Nisbett, Krantz, Jepson, & Kunda, 1983).

As one moves up the ladder from novice to expert, the ability to represent problems in terms of their deep structure improves. At the same time, the domain in memory undergoes changes in breadth and type of organization. The domain becomes organized by principles rather than superficial characteristics. Of course, experts can access many specific examples when necessary (Chi et al., 1983). However, unlike novices' schemas, experts' schemas are likely to help them **notice** and **apply** analogies. I think there are two major reasons. The first is that since the target problem will be represented by abstract principles, it is likely to cue a schema since schemas are also organized by principles. The second reason is that the cued schema is likely to be useful since problem solving is more successfully carried out by utilizing deep analogies rather than superficial analogies. Novices, on the other hand, do not have schemas or have schemas that represent superficial characteristics of problems. As a result, they will rarely **notice** a "deep" analogy since the information that gets cued by the target problem will be prior problems that involve similar surface features. Occasionally these cued problems may share

an underlying principle with the target problem, in which case the novice may be able to discover the deep analogy.

The subjects in our experiments were, in some sense, novices regardless of whether they compared or did not compare the analogs. It is highly unlikely that comparing two analogs would make one an expert. Nevertheless, some advantage was conferred on the subjects who compared the analogs. The nature of this advantage is worth exploring. One explanation would simply be that all subjects were reasoning from the specific stories to the target problem without the involvement of a schema. The reason the compare group did better is simply because they processed the stories more deeply. This depth of processing argument is weakened because the no comparison subjects in Experiment II were asked to summarize the stories twice, once while the stories were in front of them and once when the stories were removed while the comparison condition subjects only summarized the stories once while they were in front of them. Thus it seems likely that the no comparison subjects processed the stories deeply themselves.

A more likely explanation is that the comparison condition subjects may have begun to abstract the commonalities of the stories to some extent. Since they spent a relatively short time on the comparisons, 10 to 15 minutes on the average, the individual stories were probably more available than the abstract propositions which resulted from the comparison. Nevertheless, the abstract propositions could have aided in the problem solving process by emphasizing the "slots" that pieces of

the prior analogs would fill in the solution of the target problem.

It is clear that the functional relationship between schemas and the analogs from which they are created must be explored further. One question is whether schemas are applied directly to a problem or whether they serve as "pointers" to appropriate old problems in memory. In addition it seems that the roles of schemas and analogs in problem solving is an area of inquiry that overlaps with the work being done on expert/novice differences. These areas need to be integrated so that a more complete description of the problem solving process can be achieved. We are planning additional experiments in the domains of statistics and literary criticism to assess the likelihood of schema formation as a function of superficial similarity of training examples. We are also going to examine expert/novice differences in these domains by using subjects with varying expertise in these domains.

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Appendix

Analogs and Problem Used in Experiments I and II

THE GENERAL

A small country was ruled from a strong fortress by a dictator. The fortress was situated in the middle of the country, surrounded by farms and villages. Many roads radiated outward from the fortress. The general knew that an attack by his entire army would capture the fortress. He gathered his army at the head of one of the roads. However, the general learned that the dictator had planted mines on each of the roads. The mines were set so that small bodies of men could pass over them safely, since the dictator needed to move his troops and workers to and from the fortress. However, any large force wold detonate the mines. Not only would this blow up the road, but it would also destroy many neighboring villages. It therefore seemed impossible to capture the fortress.

However, the general devised a simple plan. He divided his army into small groups and dispatched each group to the head of a different road. When all was ready he gave the signal and each group marched down a different road. Each group continued down its road to the fortress so that the entire army finally arrived together at the fortress at the same time. The fortress fell and the dictator was overthrown.

THE COMMANDER

A military government was established after the elected government was

toppled in a coup. The military imposed martial law and abolished all civil liberties. A tank corp commander and his forces remained loyal to the overthrown civilian government. They hid in a forest waiting for a chance to launch a counterattack. The commander felt he could succeed if only the military headquarters could be captured. The headquarters was located on a heavily guarded island situated in the center of a lake. The only way to reach the island was by way of several pontoon bridges that connected it to the surrounded area. However, each bridge was so narrow and unstable that only a few tanks could cross at once. Such a small force would easily be repulsed by the defending troops. The headquarters therefore appeared invincible.

However, the tank commander tried an unexpected tactic. He secretly sent a number of tanks to locations near each bridge leading to the island. Then under cover of darkness the attack was launched simultaneously across each bridge. All of the groups of tanks arrived on the island together and immediately converged on the military headquarters. They managed to capture the headquarters and eventually restore the civilian government.

THE FIRE CHIEF

One night a fire broke out in a wood shed full of timber on Mr. Johnson's place. As soon as he saw flames he sounded the alarm, and within minutes dozens of neighbors were on the scene armed with buckets. The shed was already burning fiercely, and everyone was afraid that if it wasn't controlled quickly the house

would go up next. Fortunately, the shed was right beside a lake, so there was plenty of water available. If a large volume of water could hit the fire all at once, it would be extinguished. But with only small buckets to work with, it was hard to make any headway. The fire seemed to evaporate each bucket of water before it hit the wood. It looked like the house doomed.

Just then the fire chief arrived. He immediately took charge and organized everyone. He had everyone fill their bucket and then wait in a circle surrounded the burning shed. As soon as the last man was prepared, the chief gave a shout and everyone threw their bucket of water at the fire. The force of all the water arriving together dampened the fire right down, and it was quickly brought under control. Mr. Johnson was relieved that his house was saved, and the village council voted the fire chief a raise in pay.

RED ADAIR

An oil well in Saudi Arabia exploded and caught fire. The result was a blazing inferno that consumed an enormous quantity of oil each day. After initial efforts to extinguish it failed, famed firefighter Red Adair was called in. Red knew that the fire could be put out if a huge amount of fire retardant foam could be dumped on the base of the well. There was enough foam available to do the job. However, there was no hose large enough to put all the foam on the fire fast enough. The small hoses that were available could not shoot the foam quickly enough to do any good. It looked like there would have to be a costly delay before a

serious attempt could be made.

However, Red Adair knew just what to do. He stationed men in a circle all around the fire, with all of the available small hoses. When everyone was ready all of the hoses were opened up and foam was directed at the fire from all directions. In this way a huge amount of foam quickly struck the source of the fire. The blaze was extinguished, and the Saudis were satisfied that Red had earned his three million dollar fee.

PROBLEM

Suppose you are a doctor faced with the following problem. A malignant tumor has developed in the stomach of one of your patients. If the tumor is not treated soon the cancer will spread throughout the patient's body, resulting in death. Because of some medical complication it is impossible to perform an operation to remove the tumor or restrict its blood supply. There is therefore no simple way to treat the patient's condition. However, you have available a kind of ray that can be used to destroy the tumor. A sustained large dose of rays will effectively destroy the tumor. Unfortunately, at this dosage the rays will also destroy the healthy tissue that they pass through on the way to the tumor. At a lesser dosage the rays would not harm the healthy tissue, but they would not destroy the tumor either.

What type of procedure might be used to destroy the tumor with the rays, and at the same time avoid destroying the healthy tissue? Suggest as many

possible solutions as you can. Write down all the possibilities you can think of, even ones that may not really be practical. Don't worry about not having enough medical knowledge. Use any information you can think of to help solve the problem. Use the following page for writing the solutions.

Table 1

Percentage of Subjects Who Generated Convergence Solution as a Function of Stories and Instructions in Experiment 1

Group	Before Hint	After Hint (Total)	N
Two Analog Comparison	60 (12)	90 (18)	20
Two Analog No Comparison	25 (5)	80 (16)	20
Analog + Control Comparison	20 (4)	30 (6)	20
Analog + Control No Comparison	20 (4)	45 (9)	20

Note. Frequencies are given in parentheses.

Table 2

Percentage of Subjects Who Generated Convergence Solution as a Function of Instructions in Experiment II

Group	Before Hint	After Hint (Total)	N
Comparison	20 (34)	70 (121)	139
No Comparison	16 (8)	51 (25)	41

Note. Frequencies are given in parentheses.

Table 3

Percentage of Comparison Condition Subjects Who Generated Convergence Solution as a Function of Schema Quality in Experiment III

Group	Before Hint	After Hint (Total)	N
Poor	20 (16)	54 (43)	79
Intermediate	16 (11)	87 (58)	67
Good	26 (7)	74 (20)	27

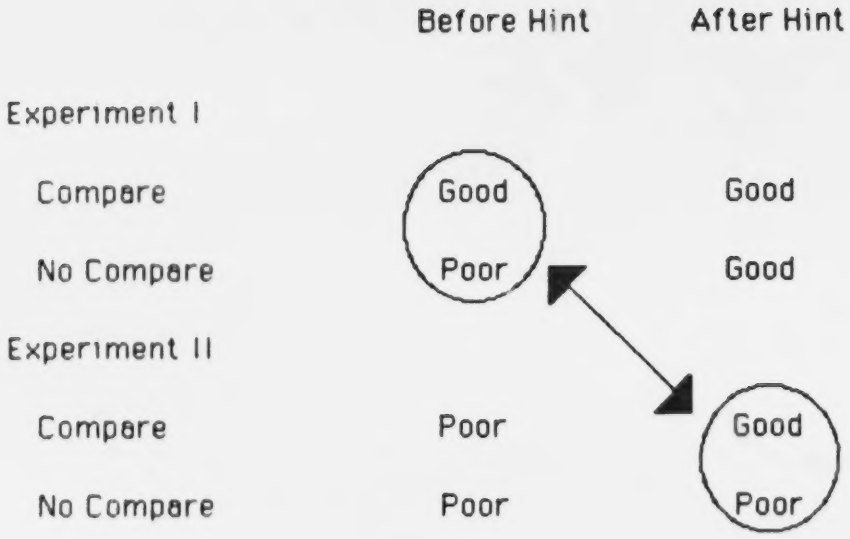
Note. Frequencies are given in parentheses.

Figure Captions

Figure 1. Design of Experiment II.

Figure 2. Comparison of the experimental situations and relative performance of subjects in Experiments I and II.

	Same Domain		Different Domain	
	Delay	No Delay	Delay	No Delay
Compare				
No Compare				


Before Hint
After Hint
Experiment I
Compare
Good
Good
No Compare
Poor
Good
Experiment II
Compare
Poor
Good
No Compare
Poor
Poor